

Modeling and Trend Analysis of Climatic Variables of Ranchi District, Jharkhand

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ABSTRACT

In this paper, an attempt has been made to study the temporal variation in monthly, seasonal and annual rainfall, and average annual maximum and minimum temperature for the period 1901-2015 over Ranchi district of Jharkhand, India. Long-term changes in rainfall, temperature was determined by Man-Kendall rank statistics and Sen's slope, and forecasting of time series was determined by ARIMA model. The results revealed that there was significant decrease of average rainfall in the month of February and August while increase in month May and Pre-monsoon season. Average rainfall in the month of February, May, August and Pre-monsoon season showing insignificant increasing as well as decreasing rainfall trend. The average annual maximum and minimum temperature showing decreasing and increasing trend over Ranchi district during the period 1901 to 2015. This paper also describes five-year prediction of rainfall and temperature climatic variables.

KEYWORDS

Mann Kendall, Sen's slope, ARIMA, forecasting and trend analysis

ARTICLE INFO

Received on	:	18/04/21
Accepted on	:	15/06/21
Published online	:	30/06/21



INTRODUCTION

Water is the major renewable resource has become a prime concern for development and planning including food production, biodiversity management, flood control and effective water resource management. According to the Intergovernmental Panel on Climate Change (IPCC, 2007) global surface warming is occurring at a rate of 0.74 ± 0.18 °C during the period 1906–2005. It has also been reported that decrease in annual average runoff and availability of water will project up to 10-30% mainly due to change in rainfall and temperature pattern. Rainfall and temperature trend analysis on different spatial and temporal scales has been become a great concern during the past century because of the global climate change from the scientific community. Zhang *et al* (2000) indicates a small positive global trend, even though large areas are characterized by negative trends. The Indian sub-continent will adversely be affected by enhanced extremities of climate, substantial reduction of summer rainfall and rising temperature in some parts and water stress by 2020 (Ma and Malini, 2003).

Study of different time series data have proved that trend is either decreasing or increasing, both in case of temperature and rainfall. Trend and magnitude of warming of India during the last century is matching with the global condition. Climate change over India by southwest monsoon causes drastic change in hydrological parameters such as rainfall, evaporation and stream flow etc., would have a significant impact of agricultural production, water resources management and overall economic growth of the country (Abeysingha *et al* 2014 and Bera 2017). Therefore, trend analysis using statis-

tical tools for long-term climatic data (i.e. rainfall and temperature) has been extensively useful in study and proper assessment of impacts of climatic change along with its variability (Duhan and Pandey 2013; Jain *et al*, 2013 and Jeet *et al* 2017). Nonparametric method of Sen's slope estimator has been frequently used to estimate the trend's magnitude, whose statistical significance was assessed by the Mann-Kendall test (Pohlert, 2016). In general, trend estimation studies for different climatic variables is determined either using parametric test or nonparametric methods ((Kumar *et al*, 2016). Previous studies have detected the significant decreasing trends of rainfall in the monsoon season, whereas during December month, significant increasing trend of rainfall have been observed in Jharkhand state ((Kumari *et al*, 2014).

A time series data must exhibit smooth behavior by avoiding inconsistent result. The most common time series model is the autoregressive integrated moving average (ARIMA) model is widely used in forecasting hydrologic and climatic time series modeling. In this model variable is forecasted by a linear combination of the previous state of variable (pure AR component), and previous forecast error (pure MA component). This model was developed for a climatic time-series forecasting model to forecast climatic variations and ARIMA model have been applied, and improved by many hydrologists for forecasting long as well as short term climate time series data ((Sultana and Hasan, 2015) and also applied in forecasting of crop production ((Kumar and Anand, 2014). The study of long term time series is critically important for food security and economy dependency on rainfall and temperature climatic parameters of Ranchi district of Jharkhand. Attempts

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have been made in the past to determine trends in the rainfall and temperature at national and regional scales ((Mali *et al*, 2017).

In the present study, a much detailed view has been taken to assess the presence of linear monotonic upward or downward trends in the temporal structure of rainfall and temperature and to quantify the trend statistics on monthly, seasonal and annual scales for Ranchi districts of Jharkhand covering all agro-climatic regions.

MATERIALS AND METHODS

Study Area

Ranchi district (Jharkhand) is situated at an altitude of 653 m above mean sea level and its extension is 23° 21' 0" N latitude and 85° 13' 48" E longitude (Figure 1). It has an area of 5231 sq. km and population of 29, 12,022 persons. The soil of the district is of lateritic and loam soil type. The majority of the soil in the area is acidic. This district receives an average annual rainfall of 1530 mm, out of which about 80 per cent rainfall was during the monsoon season. The temperature in winter season ranges from a minimum 5.3 °C to maximum 20.9 °C and in summer season ranges from minimum 20.6 °C to maximum 41 °C. The forest cover is 20.99 % of total area of the district. District has a moderate climate due to hilly region and dense deciduous forest coverage. Rice, Millets, Pulses and oil seeds is the major agricultural crops. The total cultivable area of the district is 6.1×10^5 ha, out of which 33% of the total cultivable areas is net sown area. Current fallow, other fallow and cultivable wasteland is 1.01×10^5 ha. Subarnarekha, South Koel and Sankh rivers is an important river, which runoff the excess water during the monsoon season. Only about 8 percent of cultivable land area has irrigation facility and well and canals is the major source of irrigations. Geologically, the area is comprised with Archean granites, gneisses and schists rocks type. The district have a good source of lime stone, coal, asbestos and ornamental stones etc. which provide a livelihood income source of population. The district comprises three subdivisions (i.e. Ranchi Sadar, Bundu and Khunti) and twenty development blocks.

Data used

To study the temporal distribution in climate of the Ranchi district, a trend analysis of the annual, seasonal and monthly rainfall (mm), and annual minimum and maximum temperature (°C) were considered. The monthly rainfall and annual temperature data over 115 years (1901– 2015) from two stations was obtained from India water portal (www.indiawaterportal.org) to examine the spatial and temporal variability of the rainfall and temperature data. Trend analysis of rainfall was performed for Ranchi districts of Jharkhand on annual, seasonal (pre-monsoon from March to May, monsoon from June to September, post-monsoon from October to November, and winter from December to February) and monthly basis, and trend analysis of temperature (maximum and minimum) was performed on annual basis.

Descriptive Statistics

The preliminary analysis of statistical parameters (minimum value, maximum value, mean, 1st quantile, median, 3rd quantile, standard deviation (SD), Variance, Coefficient of variance (CV), Skewness and kurtosis) of the monthly, seasonal and annual rainfall and annual temperature (1901-2015) of Ranchi district of Jharkhand was calculated by using R programming language.

ARIMA model

Autoregressive integrated moving average (ARIMA) is a method and tool for displaying and analysing univariate time series forecasts. This model is used to make forecasting, to find the best fit of a time series to past values of this time series (Li, 2009). A generalization of ARMA models which incorporates a non-stationary time-series is obtained by introducing the differencing into the model. This model is an important part of the Box-Jenkins approach to time-series modeling. A process $\{x_t\}$ is said to follow an ARIMA model, denoted by ARIMA (p, d, q), if $\nabla^d x_t = (1 - B)^d x_t$ is ARMA (p, q). The model is written in the form

$$\phi(B)(1 - B)^d x_t = \theta(B)\omega_t \{\omega_t\} - WN(0, \sigma^2) \quad (1)$$

where, WN indicating White Noise. The integration parameter d is a nonnegative integer. When d = 0, ARIMA (p, d, q) \equiv ARMA (p, q). This model is used for forecasting next five year time series by using forecast package in R language.

Mann-Kendall (MK) Test

The non-parametric Mann-Kendall test is generally used to detect monotonic upward or downward trends in climatologic and hydrologic time series. This test is applied to assess the significance of the trend of the blended time series ((Zhang *et al*, 2000). This is found to be an excellent tool for trend detection by many researchers in similar application. The Mann-Kendall test statistic is as follows

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(X_j - X_k) = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x) \quad (2)$$

where

$$\text{sgn}(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases} \quad (3)$$

It has been documented that when $n > 10$, the mean of S is $E(S) = 0$ and the variance (σ^2) of S is

$$\sigma^2 = \frac{\left\{ n(n-1)(2n+5) - \sum_{j=1}^p t_j(t_j-1)(2t_j+5) \right\}}{18} \quad (4)$$

Where, n is the number of time series data points, p is the number of the tied groups in the time series data set and t_j is the number of data points in the jth tied group. A positive value of S indicates an increasing trend, and negative value indicates a decreasing trend of time series data set.

The test statistic S is closely related to Kendall's rank correlation coefficient, tau (τ) as given by

$$\tau = \frac{S}{D} \quad (5)$$

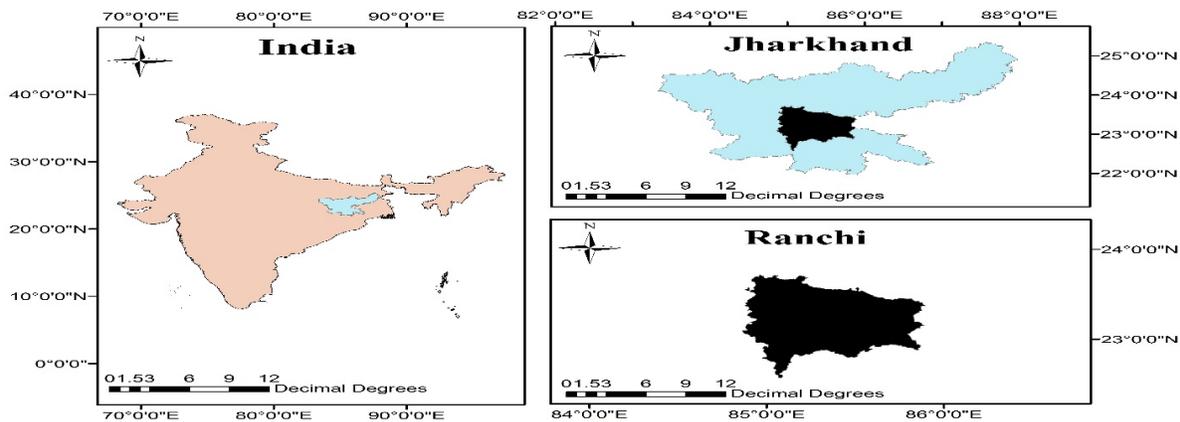


Fig. 1: Location map of Ranchi district, Jharkhand

Where, S is the Kendall score and D is the maximum possible value of S, and

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2} \sum_{j=1}^p t_j(t_j-1) \right]^{\frac{1}{2}} \times \left[\frac{1}{2}n(n-1) \right]^{\frac{1}{2}} \quad (6)$$

The Z-statistics is follows as

$$Z = \left\{ \begin{array}{ll} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{array} \right\} \quad (7)$$

The null hypothesis, H_0 , is that the data are independent and are normally distributed. The alternative hypothesis, H_A , data follows a monotonic decreasing or increasing trend.

Theil-Sen’s estimator method

This method is generally used to compute magnitudes of trend of time series data. It computes both the intercept and slope of trend of time series data. A set of linear slopes is given by following relations:

$$\beta = \text{median} \left(\frac{X_j - X_i}{j - i} \right) \text{ for } (1 \leq i < j \leq n) \quad (8)$$

where β is the slope of time series data plots, X denotes the variable, n is the number of data points, and i, j are indices. A positive value of β indicates an upward trend and the negative value of β indicates a downward trend in the time series.

RESULTS AND DISCUSSIONS

Statistical Characteristics of Rainfall (Monthly, Seasonal and Annual) and A nnual Temperature

Basic statistical parameters, such as minimum value, maximum value, mean, 1st quantile, median, 3rd quantile, standard deviation (SD), variance (Var), coefficient of variance (CV), coefficient of skewness (CS) and coefficient of kurtosis (CK) of monthly, seasonal (monsoon, post-monsoon, summer

and winter) and annual rainfall (1901-2015) and temperature (1901-2015) were analyzed and presented in Table 1 . The rainfall and temperature series for the period 1901–2015 (115 years) was tested for homogeneity, and the results showed that the rainfall and temperature time series to be symmetrically distributed for the month July, August and September, and seasonally symmetrically distributed for winter, post monsoon and SW monsoon. The rainfall and temperature of Ranchi district is symmetrically distributed throughout year.

Trend analysis

To study the temporal changes in climate of the Ranchi district, Jharkhand trend analysis of monthly, seasonal and annual rainfall, and annual maximum and minimum temperature climate variables were assumed. Trend analysis was carried out at 5% level of significance. The value of Sen’s slope and Mann-Kendall test for rainfall and temperature time series data of Ranchi district of Jharkhand estimated for monthly, seasonal and annual trend analysis and presented in Table 2. Only rainfall for month February (S=-928 and p = 0.025) as well as August (S=-971 and p= 0.019) show a significant (p<0.05) negative trend and rainfall for month May (S=973 and p= 0.018) and for Pre-monsoon season (S=815 and p=0.049) show a significant (p<0.05) positive trend. Otherwise, except month February, May, August and pre-monsoon season showing insignificant negative as well as positive trend. The average annual maximum temperature and minimum temperature also showing decreasing and increasing trend respectively. The trend analysis of seasonal and annual average rainfall for period 1901 to 2015 was depicted in Figure 2. The pre-monsoon and post-monsoon average rainfall time series (1901-2015) indicates increasing trend and winter season average rainfall time series indicates decreasing trend. The average annual rainfall time series of Ranchi district of Jharkhand indicates the decreasing trend. The increasing or decreasing trend of climatic variables would be helpful in the forecasting of climate variables in future and also helpful in district management planning.

Table 1: Descriptive statistics of rainfall and temperature

Rainfall											
Parameters	Max.	Mean	1 st Qu.	Median	3 rd Qu.	Var.	SD	CV (%)	CS	CK	
Annual	2017.20	1312.80	1176	1296.20	1422	46675.92	216.05	16.46	.37	.42	
Winter	151.83	50.31	21.17	42.18	75.14	1131.94	33.64	66.88	.67	-.17	
Pre Monsoon	225.96	87.25	53.86	79.91	114.73	2356.39	48.54	55.63	.67	-.02	
SW Monsoon	1654.40	1090.20	951.30	1087.50	1186.90	6376.01	190.73	17.49	.32	.15	
Post Monsoon	281.08	85.03	48.29	75.58	107.48	2994.88	54.73	64.36	1.04	1.16	
Jan	73.35	16.84	2.97	10.99	28.13	294.55	17.16	101.93	1.15	.68	
Feb	127.71	33.47	10.83	22.86	50.07	916.35	30.27	90.45	1.16	.57	
Mar	129.11	24.10	4.17	15.36	37.83	626.85	25.04	103.89	1.49	2.47	
Apr	84.55	22.27	6.89	16.36	29.98	397.89	19.95	89.58	1.19	.68	
May	168.35	40.89	17.49	30.85	52.93	1208.69	34.77	85.03	1.53	2.45	
Jun	525.36	190.63	115.96	172.19	249.83	9979.12	99.90	52.40	.93	.67	
Jul	639.03	325.80	263.98	317.56	388.12	9731.98	98.65	30.28	.22	.38	
Aug	615.20	361.80	281.40	358.40	432.40	10243.10	101.21	101.21	.28	-.61	
Sep	413.92	212.01	157.61	209.58	258.62	5326.11	72.98	34.42	.63	.14	
Oct	281.02	73.89	31.67	61.11	99.22	3000.13	54.77	74.13	1.12	1.26	
Nov	44.11	7.44	0.28	3.42	10.64	90.95	9.54	128.13	1.57	1.94	
Dec	29.51	3.70	0	.70	5.82	35.66	5.97	161.52	2.11	4.46	
Temperature											
Max.	28.96	31.74	30.13	29.45	30.25	30.57	.48	.70	2.31	-.02	-.79
Min.	17.67	20.27	19.04	18.52	18.80	19.95	.56	.75	3.93	.30	-1.20

Prediction and Forecasting

ARIMA model was used for forecasting next five-year time series data for monthly, seasonal and annual rainfall, average annual maximum and minimum temperature. ARIMA mod-

els are fitted on these data series for the period 1901-2015 and forecasted from 2016 to 2020. The maximum likelihood estimates, AIC and BIC of the model are presented in Table 3 and Table 4.

The results indicate that, the rainfall for month Feb, May, July, August and winter season fitted for ARIMA(3,1,3), ARIMA(0,11), ARIMA(1,0,0), ARIMA(0,1,1) and ARIMA(1,0,0) respectively and this month and season are able to forecast future times series of rainfall based on previous time series data (Table 3). Otherwise, except

above month, season and annual time series are fitted with ARIMA(0,0,0) are able to forecast future rainfall based on average of previous time series data (Table 4). For the minimum and maximum temperature, the best fitted models are ARIMA(0,1,2) and ARIMA(2,1,2) respectively (Table 3).

Table 2: Value of Sen’s Slope and Mann-Kendall test of monthly, seasonal, annual rainfall and annual temperature (1901-2015)

Rainfall						
Parameters	S	Tau	Var(S)	p-value	Sen slope	Intercept
Jan	678	0.104	171092	0.101	0.042	-72.243
Feb	-928	-0.142	171157.3	0.025	-0.137	291.851
Mar	-91	-0.014	171093	0.827	-0.007	30.751
Apr	534	0.082	171154.7	0.197	0.057	-96.852
May	973	0.148	171158.3	0.018	0.175	-310.513
Jun	339	0.052	171158.3	0.413	0.259	-341.103
Jul	165	0.025	171158.3	0.691	0.131	62.456
Aug	-971	-0.148	171158.3	0.019	-0.697	1730.028
Sep	21	0.003	171158.3	0.961	0.007	194.208
Oct	195	0.030	171158.3	0.639	0.066	-67.097
Nov	-27	-0.004	170658.3	0.949	0.000	3.419
Dec	25	0.004	162634.3	0.952	0.000	0.699
Winter	-555	-0.085	171158.3	0.180	-0.131	301.100
Pre Monsoon	815	0.124	171158.3	0.049	0.255	-422.266
SW Monsoon	-281	-0.043	171158.3	0.498	-0.382	1838.332
Post Monsoon	221	0.034	171158.3	0.594	0.066	-53.949
Annual	-169	-0.026	171158.3	0.684	-0.239	1768.896
Average Temperature						
Maximum	-2343	-0.352	175623	<0.001	-0.012	53.980
Minimum	3039	0.457	175604.3	<0.001	0.015	-11.615

Table 3: Log likelihood,AIC and BIC values of fitted ARIMA models

Rainfall												
Parameters	ARIMA Model	AR1	AR2	AR3	MA1	MA2	MA3	σ^2	Log likelihood	AIC	BIC	AICc
Feb	(3,1,3)	1.1506	-0.54	-0.23	-2.31	2.06	-0.71	853.7	-545.17	1104.3	1123.5	1105.4
May	(0,1,1)				-0.92			1189	-565.86	1135.7	1141.2	1135.8
Jul	(1,0,0)	0.1641						9563	-689.21	1384.4	1392.7	1384.6
Aug	(0,1,1)				-0.91			10079	-687.61	1379.2	1384.7	1379.3
Winter	(1,0,0)	-0.181						1106	-565.16	1136.3	1144.6	1136.5
Temperature												
Max.	(2,1,2)	0.9307	-0.31		-1.66	0.794		0.168	-59.34	128.67	142.4	129.22
Min.	(0,1,2)				-0.25	-0.33		0.123	-42.05	90.11	98.34	90.33

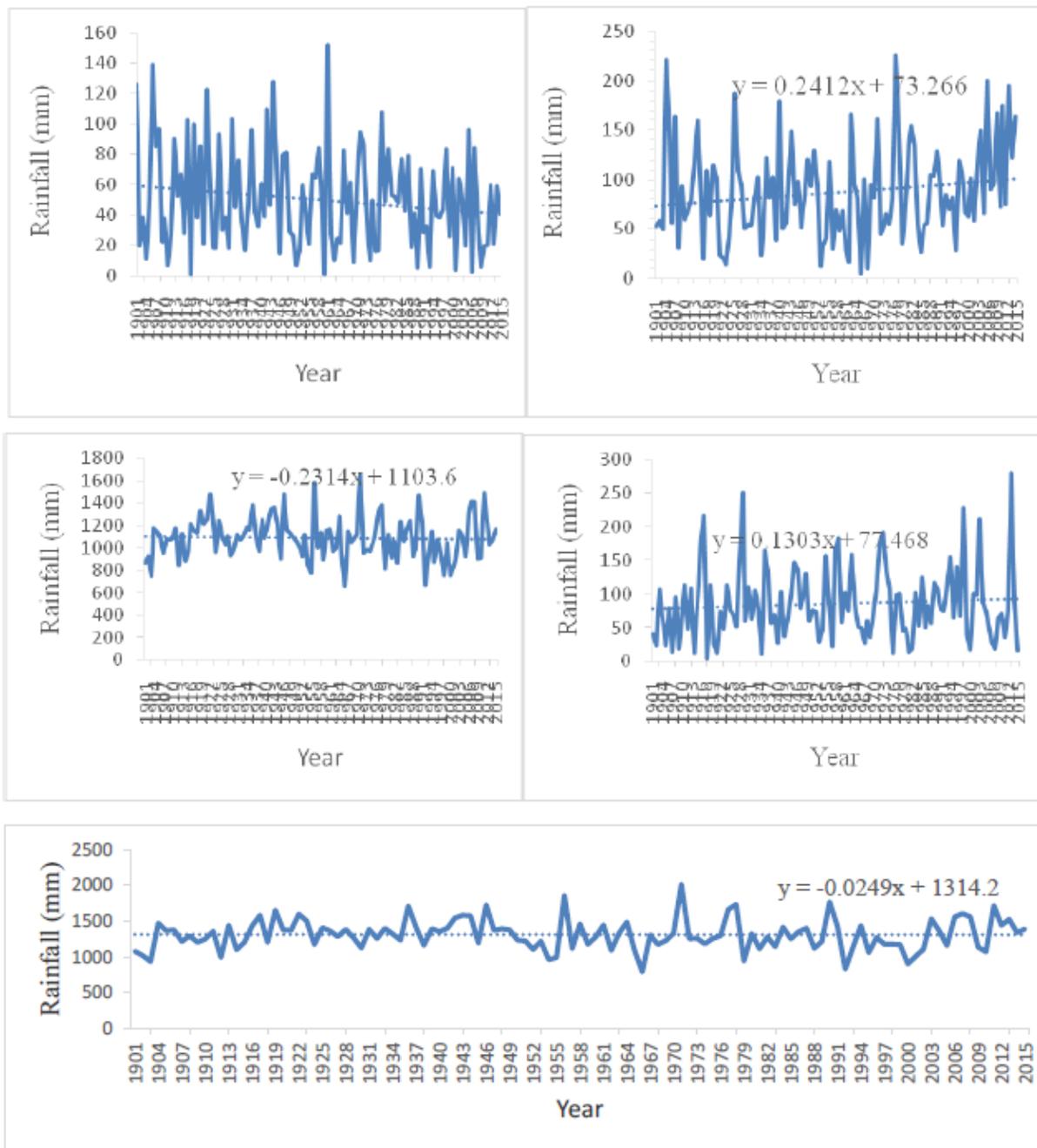


Fig. 2: Temporal variation of seasonal rainfall trend (a) Winter(b) Pre-monsoon (c) SW Monsoon (d) Post monsoon and (e) Annual Rainfall of Ranchi district, Jharkhand (1901-2015)

Table 4: Log likelihood, AIC and BIC values of fitted ARIMA model (0,0,0)

Parameters	ARIMA Model	σ^2	Log liklihood	AIC	BIC	AICc
Jan	(0,0,0)	294.6	-489.59	983.18	988.67	983.29
Mar	(0,0,0)	626.8	-533.02	1070.03	1075.5	1070.14
Apr	(0,0,0)	397.9	506.88	1017.76	1023.3	1017.87
Jun	(0,0,0)	9979	-692.15	1388.3	1393.8	1388.41
Sep	(0,0,0)	5326	-656.05	1316.09	1321.6	1316.2
Oct	(0,0,0)	3000	-623.04	1250.09	1255.6	1250.2
Nov	(0,0,0)	90.95	-422.02	848.04	853.53	848.15
Dec	(0,0,0)	35.66	-368.17	740.35	745.84	740.46
Pre Monsoon	(0,0,0)	2356	-609.16	1222.31	1227.8	1222.42
SW Monsoon	(0,0,0)	36376	-766.52	1537.04	1542.5	1537.15
Post Monsoon	(0,0,0)	2995	-622.94	1249.89	1255.4	1249.99
Annual	(0,0,0)	46676	-780.86	1565.71	1571.2	1565.82

Table 5: Forecasting for monthly, seasonal and annual rainfall and average annual maximum and minimum temperature

Rainfall prediction						Temp prediction		
Forecast	Feb	May	July	August	Winter	Forecast	Maximum	Minimum
2016	30.26	62.65	362.17	328.93	51.96	2016	29.30	19.85
2017	20.16	62.65	331.93	328.93	49.90	2017	29.33	19.87
2018	19.13	62.65	326.97	328.93	50.28	2018	29.38	19.87
2019	19.72	62.65	326.16	328.93	50.21	2019	29.42	19.87
2020	23.26	62.65	326.02	328.93	50.22	2020	29.44	19.87

Table 6: Forecasting for monthly, seasonal and annual rainfall and average annual maximum and minimum temperature

Rainfall predication												
Forecast	Jan	Mar	Apr	Jun	Sep	Oct	Nov	Dec	Pre Monsoon	SW Monsoon	Post Monsoon	Annual
2016	16.84	24.10	22.27	190.63	212.01	3.70	7.44	3.70	87.25	1090.21	85.03	1312.80
2017	16.84	24.10	22.27	190.63	212.01	3.70	7.44	3.70	87.25	1090.21	85.03	1312.80
2018	16.84	24.10	22.27	190.63	212.01	3.70	7.44	3.70	87.25	1090.21	85.03	1312.80
2019	16.84	24.10	22.27	190.63	212.01	3.70	7.44	3.70	87.25	1090.21	85.03	1312.80
2020	16.84	24.10	22.27	190.63	212.01	3.70	7.44	3.70	87.25	1090.21	85.03	1312.80

The forecasting of monthly, seasonal and annual rainfall and maximum and minimum temperature are presented in Table 5 and Table 6. The forecast values suggest that the average rainfall for month Feb, May, July, August and winter season and maximum and minimum temperature are estimated different values for next five years forecasting and for month

Jan, Mar, Apr, June, Sept, Oct, Nov, Dec, Pre monsoon, SW monsoon, post monsoon season and annual average rainfall having same next five forecasting value. The forecasted average annual rainfall of the district for the period 2016 to 2020 is 1312.80 mm which is more than the national average annual rainfall, alone SW monsoon is contributed 1090.21 mm (i.e.

approx. 80% of total avg. annual rainfall of the district) and post monsoon and pre monsoon is 85.03 mm and 87.25 mm respectively. Pre monsoon and post monsoon rainfall and temperature would help in preliminary agriculture cultivation planning. This would also be helpful in the planning and management of water resource and economic growth of the district.

CONCLUSIONS

An understanding of trends and forecasting of climatic variables (i.e., rainfall and temperature) would provide useful information for the planning, development and management of water and climate change in any area or region. The present study analyzed the climatic variable rainfall and temperature data for 115 years from 1901 to 2015 data for Ranchi district of Jharkhand state for the determination of the trend of monthly, seasonal and annual rainfall and maximum and minimum temperature and prediction and forecasting of next five year of rainfall and temperature time series. The analysis of data revealed that the significant decrease in the month of February and August average rainfall while increase in the month May and Pre-monsoon season over the Ranchi district. Except month February, May, August and Pre-monsoon season shows insignificant increasing as well as decreasing rainfall trend. The average annual maximum temperature and minimum temperature also shows decreasing and increasing trend over Ranchi district. Increasing trend in pre mon-

soon and post monsoon would help in management of water during the deficit SW monsoon seasons and significant increasing or decreasing temperature would help in forecasting of rainfall and cropping system. The average rainfall for month Feb, May, July, August and winter season fitted for ARIMA(3,1,3), ARIMA(0,11), ARIMA(1,0,0), ARIMA(0,1,1) and ARIMA(1,0,0) respectively and these are able to forecast future times series of rainfall and temperature based on preceding time series data while annual as well as monthly and seasonal rainfall time series are fitted with ARIMA(0,0,0) are able to forecast future rainfall based on average value of previous time series data. The average annual rainfall of the district for the next five is estimated to be 1312.80 mm, alone SW monsoon is contributed 1090.21 mm (i.e. approx. 80% of total avg. annual rainfall of the district) and post monsoon and pre monsoon is 85.03 mm and 87.25 mm respectively. Analyses of the rainfall and temperature data should be useful for irrigation and agricultural managers and can play an important role in managing water resources more effectively and sustainably in the Ranchi district.

ACKNOWLEDGEMENTS

The authors would like to express their deepest thanks to ICAR-IASRI, New Delhi for all their support during my Professional Attachment Training (PAT) and also to anonymous reviewer for helping in improving the quality of paper.

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Citation:

Jeet P, Singh KN, Ranjan Kumar R, Gurung B, Singh AK and Upadhyaya A. 2021. **Modeling and Trend Analysis of Climatic Variables of Ranchi District, Jharkhand.** *Journal of AgriSearch* 8(2): 120-128